DOCUMENT RESUME

ED 156 889 CE 017 245

AUTHOR Baldwin, Robert D.

TITLE Training the Electronics Maintenance Technician.
INSTITUTION Human Resources Research Organization, Alexandria, Va.
REPORT NO HumRRO-PP-7-78
PUB DATE Apr 78
NOTE 29p.; Page 17 may not reproduce well due to faint type

EDRS PRICE MF-$0.83 HC-$2.06 Plus Postage.
DESCRIPTORS *Armed Forces; Curriculum Development; Educational Theories; *Electronic Technicians; Field Studies; Job Skills; *Job Training; Learning Motivation; Performance Based Education; Problem Solving; Research Problems; Research Projects; *Trade and Industrial Education; Training Objectives; *Training Techniques
IDENTIFIERS *Army; United States

ABSTRACT

For more than twenty years controversy has existed in the Armed Forces over the kind of knowledge and training electronic maintenance technicians should have. The Navy and Air Force have conducted research projects in this area, and for the Army the Human Resources Research Organization (HumRRO) has developed several methods to improve the training of Signal Corps electronic maintenance personnel. Emphasizing a functional context approach rather than the theory and design of systems, HumRRO considered two elements to be essential to equip the student with capabilities general enough to enable him to cope with the numerous different problems he would encounter; first, the learning context must have meaning for the student based on his previous learning, and second, it must have relevance to the instructional goals. Throughout the 1950's and 1960's, HumRRO conducted numerous field studies of which the most important task projects were FORECAST, JOBTRAIN, MAINTRAIN, REPAIR, LIMIT, and a summation-type project called HAWKEYE. The results from this research into the training of electronics maintenance technicians can be generalized to the problems faced by all trainers, and HumRRO has developed a systematic and general procedure for curricular control that can be used in all job training courses. (ELG)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

Professional
Paper
7-78
HumRRO-PP-7-78

HumRRO

ED156889

Training the Electronics Maintenance Technician

Robert D. Baldwin

HUMAN RESOURCES RESEARCH ORGANIZATION
300 North Washington Street • Alexandria, Virginia 22314

Approved for public release, distribution unlimited.

April 1978

CE 017 245

U S DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

CONTENTS

	Page
Maintenance Training in Perspective	1
Early Training Concepts	1
Conventional Training Programs	1
Electronics Technician Tasks	2
Three Classes of Behaviors	2
The Decision-Making Function	2
Components of the Decision Process	2
Research Review: 1950s-1960s	4
The Military Occupational Speciality System	4
The Equipment	4
HumRRO Research and Development in Electronics Mintenance Training	5
Development of a Systematic and Generalized Procedure for Curricular Control	6
Early Research	8
Initial Projects	8
Objectives of the Field Studies	9
Findings From Field Studies	9
Some Typical Research Projects	11
Task FORECAST	11
Task JOBTRAIN	13
Task MAINTRAIN	14
Task REPAIR and Task LIMIT	15
Some General Findings and Conclusions	16
Distinction Between Education and Training	16
Some Distinctive Characteristics of HumRRO Research	17
The Functional Context Method	17
Characteristics of Effective and Ineffective Technicians	19
The HAWKEYE Project	20
Research on Basic Electronics	22
U.S. Navy Surveys	22
An Air Force Survey	23
Statistical Evaluation of Basic Electronics	24
The Military Problem Re-Visited	25

TRAINING THE ELECTRONICS MAINTENANCE TECHNICIAN

Robert D. Baldwin

MAINTENANCE TRAINING IN PERSPECTIVE

Early Training Concepts

The training programs designed for electronics technicians in the era of the 1950s and 1960s were based upon those employed for teaching electronics repairmen during World War II. During that war, the training provided for such technicians typically required one full year. This original training approach was modeled after the scientific and engineering courses at the Massachusetts Institute of Technology and was based on a course outline developed by Dr. Brown, of that school, who had done much of the theoretical work on radar. He planned a course that he thought would be appropriate for radar technicians. Understandably, since he was a system designer, his course content included the subject matter that he knew best—that pertaining to the theory and design of such systems. Such instruction placed a major emphasis on basic electronics knowledge.

Conventional Training Programs

The content of the programs for training electronics technicians (repairmen and mechanics) during the 1950s through the late 1960s was based upon the earlier MIT concepts of the knowledges and, to a lesser extent, skills required of such personnel on the job. This approach was used during that period by all of the Army's technical schools concerned with electronic maintenance training and is still used by some schools in all the armed services.

The conventional sequence of instruction had the following characteristics:

(1) Instruction in basic principles of electricity and electronics preceded instruction on intact equipment. Specifically, the instruction utilized a "part-to-whole" approach, in which the sequence of topics parallels the building up of a radio set, beginning with simple circuits which then are combined into successively more complex assemblies as the course unfolds.

(2) In general, instruction on maintenance principles and techniques followed instruction on the principles of electronics. That is, the student was expected to know the principles of equipment functioning before he was taught troubleshooting and repair skills.

Generally speaking, such a sequence conforms to standard educational practice. It most closely resembles the sequence in the education of electrical and electronics engineers. Advocates have defended it on the grounds that it is necessary for students to master general principles of electronics as a prerequisite for understanding circuits embodying those principles and for learning troubleshooting skills. In more general terms, it represents a deductive approach to instruction.

The "part-to-whole" or deductive approach probably derives some of its support from an analogy with the relation between school and job. School instruction presumably

equips the person with general capabilities that enable him to cope with the multitude of particular requirements imposed by the job. In the military setting, a technical course is expected to yield a versatile repairman whose abilities extend to the maintenance of a wide variety of equipment and even to the design and construction of new equipment during emergencies. Similarly, the education of the electrical engineer is aimed toward development of potential for the design of new equipment. This "theory first - application second" characteristic seems to have been the pattern for the conventional sequence of instruction.

ELECTRONICS TECHNICIAN TASKS

Three Classes of Behavior

Electronics maintenance repair is characterized by a wealth of job-oriented behaviors, most of which can be treated within one of three major classes: (a) *mechanical behaviors*, such as disassembling and/or assembling components, removing and replacing piece parts, and soldering; (b) *operator behaviors*, such as energizing the system, energizing components apart from the system, switching, and monitoring; (c) *decision-function behaviors*, upon which each choice of action is based. The selection of a particular test, or a decision to replace a particular part are examples of job-oriented behaviors within the third classification.

The Decision-Making Function

Among maintenance behaviors, those relating to the decision function stand out as primary contributors to system maintainability. This is true even though the mechanical skills necessary to effect a repair, once the malfunctioning piece-part is identified, must always be present. For electronic systems, it is usually the diagnosis rather than the part replacement that accounts for the largest portion of the system "down time" for which the repairman bears responsibility.

Decision making has both an active and a passive aspect. Information, stored and recalled as needed, comprises the passive aspect. Sensing, recognizing, and interpreting events comprise the active aspect. Although the active aspect always implies a man, the passive need not. Information can be stored separately from the man in job aids such as books, charts, tables, and written formulations.

The information stored inside the man himself is referred to as experience. The formation and modification of experience is the province of training. Training must take into account the nature and amount of infomation available in job aids, because this will always determine the nature and amount of experience that must be provided.

Job aids that are well mated to experience can simplify training and keep the performer operating at a level of complexity where error is not excessive. Job aids and experience that are mismatched can make performance very costly in terms of both error rate and the time required to train. Because of this effect, a closer examination of the experience and actions demanded of the decision maker is in order.

Components of the Decision Process

In Gagne's treatment of the relationship between human information processing and action, the active aspect of decision making is represented by the sensing, filtering,

identifying, interpreting, and inventing mechanisms, while the passive aspect is represented by the long and short term memory.

Among the active components, not all mechanisms are performed equally well. In general, human beings are very good at *sensing* and *filtering* events even though machines capable of sensing and filtering some types of events much more finely than human beings have been constructed.

With respect to the *identification* mechanism, however, man still shines. The brain has a high tolerance for input variations within a class. It also has rapid access to comparative data whereas a machine programmed to identify has to sort through its entire memory in serial order. The machine may also reject or misclassify events that the brain recognizes as being only slightly different.

When the human *interpretation* mechanism is utilized, performance costs in terms of increased error rate can be substantial. When required to make interpretations, human performers tend to jump to conclusions based on an inadequate number of observations, to overlook data and possible interpretations even when these are available in the long term memory, and to make mistakes even when the necessary inferences are prescribed by a set of rigidly defined rules.

The term "inventing" stands for a highly regarded function in our society but, in practice, the employment of the *inventing* mechanism is quite inefficient. To be characterized within this class, the formulation of rules, approaches, or "short cuts" need only be novel with respect to the person concerned. To more sophisticated persons, these rules and approaches may be trite or inefficient. In almost every case, the inventing function is essentially a trial-and-error process.

The decision-making process can be illustrated further by examining the way in which it is called into play in troubleshooting electronic equipment. For example, at some point in the repair process, the repairman may need to examine the output, displayed on an oscilloscope, of a small collection of parts. The decision function commences when the repairman directs his attention toward or *senses* the oscilloscope display. He employs *filtering* when some instruction, such as "ignore the envelope and look for the synchronization pulse," is called from the *short term memory*. At this point, he extracts comparative information from the *long term memory* in the form of synchronization pulse characteristics. Using this comparative information, the repairman *identifies* the sensed and filtered event as a good synchronization pulse, or as a distorted or missing pulse.

The next step in the process requires an *interpretation* of the event by applying a set of rules to the class of events identified. If the repairman has been conventionally trained, and if he is using conventional job aids, a set of rules for making an interpretation will not be directly available. Instead, the job aid will provide a description, in the form of a schematic, of the way in which the equipment is constructed. On the basis of this information, the repairman must, using his experience, formulate his own set of rules for treating the event he has identified.

Note that the traditionally trained repairman must, in effect, reconstitute circuits in his mind, working backward from the symptom he identified to the altered circuit characteristic that could result in this symptom. This is human functioning of the highest order and is equivalent to, in some cases, the inventing mechanism originally required to design the circuit. It is also expensive, since training time as well as error rates become excessive when the more complex decision-making mechanisms are the rule.

Human beings perform the identification mechanism well. If job aids and training could be so constructed that the greatest burden of decision making during troubleshooting falls on the identification mechanism rather than upon the interpretation and inventing mechanisms, it seems reasonable to expect that training efficiency and effectiveness could be enhanced.

The behavior of repairmen in the field suggests that the identification mechanism is being employed on a more or less haphazard basis. An experienced maintenance supervisor, when assisting a novice, is likely to provide cues to the type of information he himself uses to solve troubleshooting problems. He tends to say things like, "Didn't you notice that the alarm unit is not functioning properly?" or "Didn't you notice that the manual regulator control has no effect?" Apparently he has learned, over the years, to recognize certain "diagnostic" consequences that are characteristically associated with certain classes of failure. This may be how repairmen have improved their performance as they gained experience on the job. Perhaps they have been reprogramming their long term memories with an array of symptom-part relationships, and are then choosing the part to be investigated through the application of the identification mechanism.

Once a defect has been repaired, the experienced technician can always produce a theoretical rationale to suit the situation. The multiplicity of competing analyses (often defended at great length and with a good deal of heat) produced by three or four technicians who are jointly considering an as-yet-unsolved problem suggests that the solution may lead to the rationale rather than vice versa.

RESEARCH REVIEW: 1950s-1960s

The Military Occupational Specialty System

The jobs for which the U.S. Army maintenance men are trained tend to be specific and circumscribed. There are more than 80 different military occupational specialties involving electronics maintenance.

The Army makes a distinction between (a) direct support or field and (b) organizational maintenance. Organizational maintenance generally involves overall maintenance of the system down to the level of the replaceable chassis. Some intra-chassis troubleshooting is authorized for the organizational maintenance man, but this generally is the task reserved for direct support or field maintenance. In some instances the field maintenance man will be trained on a specific subsystem of a complex missile system. Thus he alone would not necessarily be responsible for repairing all chassis sent to his direct support unit by the organizational maintenance man.

Some repair, such as rebuilding chassis, has to be done at a rear echelon depot area. This work is often carried on by Department of Army civilian maintenance specialists rather than by enlisted personnel. The combat arms centers teach organizational maintenance, while Ordnance, Signal, and Engineer schools teach field maintenance.

Upon completing an electronics maintenance course, the graduate is usually sent to an operational unit to perform the duties for which he was trained. The unit commander, however, has some latitude as to how he will use the man. The graduate may serve in a unit based in the continental United States or in any one of several theaters in which Army personnel are deployed. Some theaters conduct further formal training of the new graduate upon his arrival prior to assigning him to an operational unit.

The Equipment

The kinds of equipment for which formal electronics maintenance training is given cover a broad range of size and complexity. A field radio repairman may be responsible for higher echelon maintenance of as many as 20 different radios, ranging from hand-held radios to those mounted in armored vehicles. In contrast, in a typical Hawk Air Defense

battery and its associated direct support unit, you will find a half-dozen different electronics maintenance specialists. Some perform organizational maintenance tasks, others perform field maintenance tasks. These men may work on computers, or missile guidance systems, or inter-communication equipment, or radars. A typical higher echelon maintenance man in many missile systems would be required to have a detailed technical knowledge not only of system calibration and tuning, but also of the inner workings of over 100 individual chassis.

HumRRO Research and Development in Electronics Maintenance Training

In the 26 years of HumRRO's existence, about 50 man-years of the total HumRRO effort has been devoted to research on electronics maintenance training. In this work we have employed psychologists, engineers, an occasional physicist, and a goodly number of skilled electronics technicians. As with most of HumRRO's military training research, the subject matter expertise comes from specialists in electronics, while the scientist conceptualizes the problem, develops the research strategy, and plans the scientific design and analysis of the study.

In work of this nature there is a need to distinguish between the concept of training and the concept of education. Both terms have been applied to the process of human learning, frequently with little differentiation. There is, however, a critical distinction. Training is any set of more or less formally organized learning experiences designed to prepare an individual to perform certain acts that are specifiable in advance. If the acts to be learned cannot be specified in advance, for whatever reason, a set of similarly organized learning experiences is called education. In the case of training, learning can be sharply focused on the later job behaviors. In the case of education, the learning experience must be devoted to providing an individual with a background of knowledges, skills, and attitudes relevant to requirements that may be imposed following learning.

As an example, an individual can be trained to operate a simple machine on a production line. There would be very few production lines, however, if no education of individuals in the general fields of the sciences and engineering had taken place previously. The operator is trained; the designer and the manager of the production line are educated.

Early research in electronics maintenance training, including our own, conceived of troubelshooting or faultfinding as problem solving. Thus, this most challenging part of maintenance was thought to be not really amenable to training, as all the problems likely to be encountered could not be specified in advance. However, recent and sophisticated research has demonstrated that any electronic equipment can be analyzed (from prototypes and/or drawings where necessary) to determine the population of troubles that may occur. Once this is done, it becomes reasonable to train personnel in procedures to handle the already specified population of troubles.

HumRRO's electronics training research activities have been concerned with five major questions:

(1) *What does the electronics man actually do on the job?* What are the tasks he must perform, in what context, with what equipment and job aids? The research problem here is to develop techniques and procedures by which jobs can be accurately and efficiently described.

(2) *How well can the graduate perform the task?* How well does he perform after specified periods of experience on the job? The technical problem for the researcher here is, that of developing effective and efficient ways of assessing a man's proficiency—that is, his capability to perform the job.

(3) *By what training methods* and with what training media *can the skills and knowledges required be most effectively taught?* That is, of course, the main area of concern for most experimental psychologists—human learning.

(4) *What kinds of training aids*, manuals, guides, and so forth, *are most effective* and in what form, in order to provide the essential technical support for performing electronics maintenance tasks?

(5) *How should the job be designed?* What kinds of tasks should be grouped with what other kinds of tasks to make a military occupational speciaity?

Development of a Systematic and Generalized Procedure for Curricular Control

The major lesson HumRRO has learned in its studies of electronics maintenance training is the need for a systematic, generalized procedure for building and testing training courses. The procedure we have evolved represents an amalgam of many researchers' thoughts and concepts. There are seven points in this procedure, as shown below.

The Technology of Training

1. Determine job performances required.
2. Derive training objectives from job performance requirements.
3. Base training content on training objectives.
4. Select appropriate training methods.
5. Administer training appropriately.
6. Monitor the trained product.
7. Modify training as required.

(1) *Determine job performances required.* To be effective and efficient, training must be derived from job requirements. The initial and most critical step in developing any training program is to specify and describe what the individual must know and be able to do on the job for which he is being trained. This does not necessarily mean either a description of how the job may be currently performed or a reflection of current training. A good job description must satisfy the purpose for which the job was established in the military system. In other words, it must define the way in which the job should be performed. The purpose of training is to develop human performance capabilities. Therefore, we have to know, in detail and on a continuing basis, just what human performance capabilities are required. If one accepts this first step, the next six logically follow.

(2) *Derive training objectives from job performance requirements.* Once performance requirements have been determined the next step is to derive corresponding training objectives that specify what tasks the trainee must master, and to what level of proficiency. Quite naturally, this tightens the existing control procedures. Properly established training objectives serve as a standard against which training effectiveness can be evaluated. They also provide much more effective management control, as will be demonstrated.

Many considerations enter into determining training objectives—nature of the manpower pool, cost of training, urgency for getting the trained men on the job, adequacy of training facilities, and the relative merits of school versus on-the-job training. But the critical ingredient of a training objective is still the performance required.

(3) *Base training content on training objectives.* The content of training (that which is taught) is based on the objectives. The more specifically the objectives are stated, the easier it is to identify content for training. A major problem arises in distinguishing between that content which is essential and that which is desirable, but not essential. This problem can be attacked in several ways; no single way is completely adequate. Where abstract or conceptual knowledge seems needed, an earnest attempt should be made to restate such knowledge in specific items of information required for job performance. Only after training content has been determined should full attention be devoted to selecting instructional techniques and training aids. We must know *what* to teach before we can realistically determine *how* to teach it.

(4) *Select appropriate training methods.* Most training content can be presented in a great variety of ways. There is no single way to produce the most efficient learning for the wide variety of required military performances in electronics maintenance. Intensive research efforts have been directed toward finding effective ways to organize and sequence training content and to select appropriate training and teaching methods. From this research have come several general concepts and "rules of thumb" about which we will talk later.

(5) *Administer training so as to minimize interference with learning and maximize learning principles.* Administration of the training program is an important aspect of curricular control. The school system must be organized and run to insure production of the required performances. Scheduling of classes and work details, providing for knowledge of progress by the students, arranging for appropriate and realistic practice of skills to be learned, emphasizing student performance as opposed to completing progress charts, and integrating classroom, laboratory, and field instruction, are all relevant to the administration of training.

(6) *Monitor the school-trained product.* Once training has been completed, two related questions should be asked. (a) How proficient is the graduate in performing the job? (b) How effective is the training program? We know of only one dependable way to answer these questions—by conducting an objective evaluation or quality control program. The general goal of such a program is to determine whether training activities are responsive to performance requirements. This program can serve many purposes, such as (a) estimating how well training objectives have been met, (b) determining where additional or modified training is necessary, (c) informing the trainee about his performance (this information also has motivational benefits), (d) providing information for individual job assignments and possible future career training, and (e) determining the effectiveness of student selection procedures.

Any school training system must contain a mechanism by which its effectiveness can be continuously assessed. Lack of such a mechanism will deny the school needed information, will permit a deficiency to go undetected, and will adversely affect the economy of training. A quality control office, independent of instructional departments, can bridge this particular gap and close the information loop. The objective to be served by the quality control group is to develop and administer job-based performance tests and to inform school administrators of the test results.

(7) *Modify training as required.* At least two sources provide information on which modification of the training program should be based:

(a) The current status of required performance. Has the job changed? If so, how? Do these changes delete some of the originally required performances? Do they add others?

(b) The data obtained from the quality control function.

Training programs should be continuously modified to reflect such changes in job performance requirements and to eliminate any deficiencies revealed by the quality control system.

EARLY RESEARCH

Initial Projects

Interest in conducting research on electronics maintenance training was simulated in part by a survey of the Artillery School, Antiaircraft and Guided Missiles Branch, Fort Bliss, Texas, conducted at the request of the Office, Chief of Army Field Forces (OCAFF), by a Special Survey Commission set up by the Human Resources Research Office during the summer of 1952. Among other things, the report on the findings of the survey commission[1] showed the need for information on field activities of Army electronics personnel. A proposal outlining a general research program concerned with the training of radar repairmen and radar operators was approved by OCAFF in March 1953. In the concurrence, OCAFF recommended that "all radar operators and maintenance in the Army including arms and services should be included" and that "the relationship of radar maintenance to radio maintenance and the maintenance of other electronics devices used by the Army should be considered."

The research objectives included ascertaining (a) the problems of radar and fire control system maintenance in the field, (b) the knowledge and skills required by the radar mechanic to perform his job efficiently, and (c) the feasibility of training dual-level radar mechanics for units equipped with electronic fire control sytems.

As a first step, relevant literature[2] was surveyed and field trips were made to Army, Navy, and Air Force installations and their contractors to collect information on relevant work completed or in progress.

The AAFCS M33 mechanics and operators were selected for a first study in this general area and a report of the field activities and problems was made.[3] A HumRRO research group, working with the AA & GM Branch, developed a field proficiency test for the AAFCS M33 radar mechanic. This test, designed to be administered on the actual M33 equipment, was given to radar mechanics immediately upon graduation from the school at Fort Bliss and to experienced mechanics assigned to AAA installations. The test instrument was used to evaluate experimental course modifications in the school training program. The analysis of the maintenance behavior observed during testing, both at the school and in the field, provided information valuable to personnel responsible for modifying training programs. In addition, data gathered during the test administration provided information on factors related to effective and ineffective troubleshooting behavior.

The Office, Chief of Ordnance, requested a study of the Ordnance Integrated Fire Control detachments performing higher-echelon maintenance on the AAFCS M33 and T38 systems. A field study of these repair teams in the continental United States, the Far East, and Europe was initiated in 1954.

The Office, Chief Signal Officer, requested research on the training of radio electronics personnel both at the school and on the job. Following a tryout of data-gathering techniques with two Signal units at Fort Bragg, North Carolina, a field study of field radio repairmen and VHF personnel (MOS 1648) involving about 300 individuals at nine major U.S. installations was completed in December 1954. Data on about 300 repairmen in USAREUR also were gathered. Initial developmental work on a proficiency

[1] *Survey of the Educational Program of the Artillery School, Antiaircraft and Guided Missiles Branch, Fort Bliss, Texas*, HumRRO Special Report 1, December 1952.

[2] Abram M. Barch, *et al. A Bibliography of Human Factors in Radar Operation and Maintenance*, HumRRO Staff Memorandum, September 1953.

[3] *The AAFCS M33 Mechanic: Analysis of Field Activities and Problems With Implications for Training*, HumRRO Information Report, March 1954.

test battery for the field radio repairmen, based on information available from the field study, was carried out at Fort Meade, Maryland. More intensive work on the test instrument was completed at the Signal School, Fort Monmouth, New Jersey.

These three projects represent three different kinds of electronics maintenance research studies. This discussion is primarily concerned with the *field study phases* so we will not report the details of the total research programs. However, it may be noted that, although all three were concerned with the one broad objective of improving personnel training and performance, the specific problems and objectives differed from one project to another.

The differences were due to certain unique considerations and goals prevailing in each training situation. For example, in the AAFCS M33 radar repairman course at Fort Bliss, one individual was being trained to assume responsibility for the first and second echelon maintenance of a particular item of operational equipment. On the other hand, the Signal Corps trained a radio repairman who in the field might find himself responsible at various echelon levels for the maintenance and repair of radio equipment on which he may never have been trained. For this reason, the Signal Corps project dealt ultimately with such problems as determining the minimum and most effective basic core of instruction that would yield maximum transfer of critical skills and knowledge required for maintaining a wide variety of radio equipment. In the case of the Ordnance research, we were concerned with a group of men with different MOSs functioning as a team to carry out the higher echelon maintenance of a particular complex electronic system.

Objectives of the Field Studies

The field study phases of our research were designed to obtain, by activity analyses, a detailed account of the field activities, problems, and difficulties of electronics maintenance personnel, and to analyze the data obtained in terms of their training implications. We were particularly concerned with those elements of the job for which formal school training, for whatever reason, did not adequately prepare the individual, and conversely with those aspects of formal training that did not appear to be relevant for adequate job performance.

Some of the more specific aims of the activity analyses were as follows:

(1) To transmit to military training authorities data which represent a source of current information about field activities and problems of maintenance personnel, and which may be used as a basis for reviewing training requirements.

(2) To provide information to be used in the development of measures of proficiency, for example, knowledge of the range and frequency of job activities, items of equipment to be obtained, and types of malfunctions encountered in the field.

(3) To obtain a broad view of the activities, problems, and difficulties of field repairmen that may provide a basis for selecting critical areas for subsequent research, for example, training methods, curriculum modification and evaluation, on-the-job or unit training, and troubleshooting procedures.

Findings From Field Studies

One of the most significant general findings was the virtual absence of systematic on-the-job training programs in any of the maintenance areas studied. This point was particularly noteworthy in view of the position frequently taken by schools that their graduate is not a "finished" repairman. The statement is made that the school graduate will have a broad base of relevant, general knowledge and theory that will enable him more readily to develop into a proficient maintenance person with appropriate on-the-job training and experience.

The assumption that newly arrived personnel will be trained by the men they replace was and still is not tenable, in view of the fact that when a relatively small number of men hold a given MOS, experienced personnel have departed before replacements have arrived. This situation often results in the loss of much useful information concerning the idiosyncrasies of individual sets. Also, a restraint on the adequate training of new personnel is the view of many supervisors that the possibility of damage to operational equipment is too great for it to be used for on-the-job training. Equipment for training purposes is usually not available. It seems that an important hiatus exists between the completion of school training and transition training for the man newly arrived on the job, and continuing systematic on-the-job training. There may be, and probably should be, marked differences between school and unit training with respect to instructional content and methods.

Some important findings were specific to a particular study. For example, it was found that Signal Corps radio repairmen, particularly in the United States, were largely inactive for varying periods of time, particularly during the period immediately following graduation, when they actually engaged in little, if any, activity requiring the application of school training. This was due partly to the extensive utilization of civilian personnel for radio repair.

Another finding, specific to the study of AAFCS M33 personnel, dealt with the role that operators played in maintenance. Of all the malfunctions obtained, it is noteworthy that in almost half of the cases, symptoms were first observed and reported by the radar operators. These personnel, it was found, also often assisted the radar mechanic in performing preventive maintenance, including daily checks and similar activities. Such findings pointed up the necessity of studying not only men specifically designated as maintenance personnel but also those immediately associated with the equipment as operators and in other capacities in relation to the mechanic.

Another more general finding concerned factors that determine or affect the echelon of maintenance that is performed, regardless of the level officially prescribed for various maintenance personnel. By and large, personnel in all of our studies appeared to spend the greater proportion of their time performing at a fairly low echelon maintenance level relative to the authorized levels for which they had been trained. Those responsible for first and second echelons spent most of their time in relatively simple activities. Those trained to support the lower echelons of maintenance worked a great part of the time at the first two echelons. The higher echelon maintenance duties of certain repairmen studied were performed largely by civilians. The actual level of maintenance performed depended on several factors, including (a) availability of necessary spare parts, and in some cases, necessary test equipment, (b) inability to do the work because of lack of knowledge, (c) permission and availability of necessary parts from higher echelon personnel to lower echelon personnel, (d) individual initiative, and (e) local administrative practices that preclude certain levels of maintenance.

It is also important to realize that the actual level of maintenance performed by an individual varied from time to time as a function of level of personnel available. Where there was a shortage of lower-level persons, lower echelon responsibilities were assumed by the more highly trained man and vice versa. Experience and time on the job was another determinant. In one study, according to the judgments of both commanding officers and field representatives, individuals originally trained as helpers functioned satisfactorily as repairmen after about seven months of field experience while individuals originally more highly trained as repairmen required approximately three months of field experience to function at this same level of effectiveness.

SOME TYPICAL RESEARCH PROJECTS

Over the extensive period in which HumRRO has been engaged in electronics training research, there have been approximately a dozen separate research activities, each undertaken by a different research team. It is interesting to note that while the different teams began with quite different approaches to the problem of improving electronics maintenance training, in the mid-1960s a consensus developed. In part, it derived from empirical determination that certain things tend to work in a variety of contexts. In part, it was a function of improvements in the design and engineering of electronics systems. In part, continued discussion among the researchers themselves brought about a better understanding of differences and similarities in research approaches.

From this group of research tasks we have selected five examples that typify the state of the art in the training of personnel for the maintenance of Army electronics systems. These are older research projects because very little research on training electronics technicians has been conducted in recent years.

Task FORECAST

In FORECAST, the development of improved training courses was approached by means of analysis in terms of cues and responses—what the man perceives and what he does about it. The objective was to produce training content that (a) is based on the kinds of information available *about* new weapons systems before they have been produced (such as schematic diagrams), and that (b) will result in effective job performance of the operation and maintenance tasks in a man-machine system.

Early efforts in Task FORECAST were concentrated on operator training, such as turning on and tuning a radar system. Researchers soon found that they could readily develop simple techniques that would produce a minimally acceptable operator in a period of time as short as one day. Then they developed a variety of other techniques by which fixed procedures could be taught quite rapidly, using simple and inexpensive training aids and devices rather than the hardware itself. FORECAST research was soon re-directed toward the study of electronics maintenance.

The research staff developed a technique of analyzing electronic systems that provides the means for organizing the system conceptually so that a strict troubleshooting logic will hold throughout the system. This logic does not hold true in electronic systems unless this conceptual organization is accomplished. Simple troubleshooting logic can be illustrated in this way:

In a linear data flow chain of blocks, if the input to block B is good and the output is bad, then the trouble is in B. In electronic systems, however, this is not necessarily true because of feedbacks, reflected troubles, and other characteristics of electronic circuits caused by the trouble in another block of the system. Traditionally, repairmen have been given sufficient theoretical training in electronics to enable them to deduce and then compute these kinds of exceptions.

In Task FORECAST another approach was taken—that of analyzing the system so as to make the logic work without exception. When the analysis, called cue-response, was made by expert personnel using FORECAST guidelines, the simple troubleshooting logic did hold true. This allowed a block diagram approach to be effective for actual troubleshooting rather than for just simple explanations. Thus, the repairman could respond to a cue as a straightforward and reliable indication of what troubleshooting procedure he should follow.

This cue-response approach to the analysis of complex weapon systems was tested on the M33 integrated fire control system and different Nike missile systems, as well as on U.S. Navy shipboard LORAN radar. More detail on FORECAST techniques is provided in HumRRO published reports. Some of the more important findings can be summarized as follows:

(1) Training based on the FORECAST type of equipment analysis, using the cue-response paradigm, resulted in effective job performance, with a decrease in training time on the operational and maintenance tasks in an electronics system. This has been demonstrated in three studies, including one in which graduates of a 12-week FORECAST course performed as well as those of the 30-week traditional course.

(2) Studies of transfer of training, in which students trained on one subsystem of an integrated fire control system were then tested on another subsystem on which they received very little training, indicate that FORECAST training can transfer across electronic systems. What is suggested by these transfer studies is that a course employing FORECAST electronics maintenance training allied with a series of systems-specific programs could be used for producing multi-system competence within a reasonable period of time. Remember, we are talking about "a reasonable period" in terms of a three-year enlistment.

(3) A study of electronic system mockups suggested that maintenance proficiency can be increased by the use of such troubleshooting training devices. If they are based on task analysis and are properly designed, they can be used for teaching certain of the skills and knowledges required of the repairman, particularly those needed to carry out the cognitive activities of troubleshooting. Incorporation of such devices in training programs can reduce the requirements for more costly electronic equipment. Even if this equipment is available, some portions of electronics training can be done more efficiently using mockup devices.

(4) FORECAST techniques were used successfully to develop training content from the kinds of information available about new weapon systems before they are in production. For the three studies mentioned above, the experimental courses were developed from schematics and other pre-production materials and then tested on the operational equipment. In a study of the improved Nike-Hercules HIPAR radar, the equipment was analyzed by the FORECAST method one year before it reached the field and effective training was derived for portions of the final course of instruction.

(5) Military technicians were taught to apply the FORECAST methods of analyzing equipment, and the materials that they developed provided a basis for effective troubleshooting. The analysis was packaged in a simple, usable form that strikes an effective balance between what the troubleshooter keeps in his head and what he has in his hand for reference. Among the products of the FORECAST analysis applicable both for training and as job aids are (a) a block diagram of the system; (b) a narrative description of the system signals which provides the basis for integrating and understanding symptoms and symptom patterns; (c) identification of dynamic signals at selected checkpoints; (d) schematic diagrams logically blocked for troubleshooting to show the boundaries of the system circuits where it is efficient to change from dynamic to statis checks; (e) a set of static checks for within-block checks of parts.

Proportionately, more effort was placed on FORECAST activities than on any other single electronics training research project. HumRRO worked on FORECAST for over eight years. It may well be asked, therefore, what effect it has had on electronics maintenance training in the U.S. Army. The answer is that FORECAST concepts have not been completely accepted to date. Perhaps the philosophy was a bit too radical a departure from traditional concepts. Some trainers felt that electronics training had already moved too far away from electronics education. However, there has been utilization of some of the FORECAST thinking and some of the FORECAST products both in

the Army and in the Navy. Blocks of instruction used in Nike electronics maintenance training were adopted or adapted from FORECAST systems troubleshooting materials. Inexpensive mockups have been developed and improved through use in Army training programs. The Navy adopted a two-week FORECAST-developed LORAN maintenance training course *in toto*. Finally, many of the basic characteristics of the FORECAST approach have been found in industry proposals for the development of new-style technical manuals.

Task JOBTRAIN

The objective of Task JOBTRAIN was to develop a combination of training and job aids or manuals for field carrier equipment repairmen that would require less training time than the combination of the standard course of instruction and conventional manuals.

The principal product was a method of analyzing existing electronic communication equipment. This method produced a troubleshooting strategy for the equipment analyzed and specific information to support that strategy. Perhaps because the equipment was different from that involved in air defense systems studied in FORECAST, the troubleshooting strategy developed for the equipment analyzed differed somewhat from the FORECAST strategy.

On the basis of the study of repairmen in the field performing maintenance on carrier equipment, the strategy selected was that of training electronics repairmen to recognize symptoms of illness. The physician does not base his diagnosis on the normal functioning of the human system, nor is he primarily concerned with the biological processes involved. He is, instead, skilled in noticing the distinctive and/or obscure symptoms that define the disease. Similarly, the JOBTRAIN research proceeded on the premise that it would be possible to provide the electronics repairman with the experience and information necessary to recognize, rather than to infer, malfunction causes.

The rationale of JOBTRAIN can be stated as follows:

(1) Efficient and effective training can be designed and evaluated only if the specific tasks required by the job are identified.

(2) Among electronics maintenance tasks, the decision-making function is critical.

(3) It is possible to construct job aids in training that will support the repairman in the decision mechanism which human beings perform best—that is, identification. We use the term "identification" to contrast with invention and interpretation, which are also critical elements of the decision-making process.

(4) It is feasible to separate troubleshooting information into that which is best stored in the job aids (information specific to the equipment) and that which is best stored in the individual's memory (general information).

The method of analysis was then applied to ten items of equipment maintained by field carrier equipment repairmen. Experienced repairmen performed this analysis operation under the guidance of the research staff, and then also prepared job aids and the course of instruction. The course was 420 academic hours in length, in contrast to a standard 856-hour course for this particular military occupational specialty. The experimental course required no more hours of training on equipment than did the standard course. In the experimental administration the JOBTRAIN course was taught by most of the same personnel who made the initial analysis of the equipment and developed the job aids.

During a six-day testing period, graduates of the JOBTRAIN course were required to troubleshoot 18 malfunctions placed in various items of equipment. They were also tested on their ability to align, remove and replace, name and locate, and make final

tests on the equipment. Graduates of the conventional course, matched to the JOBTRAIN students in background and aptitude factors, were tested on the same test at the same time. Testing was administered by a special group of school instructors—an experimental procedure commonly used in HumRRO research.

The results of this testing showed no significant differences between the two groups of men. It appeared that the combination of JOBTRAIN training and job aids was as effective as was conventional school training and manuals, but the JOBTRAIN approach required only half as much academic time. This finding supports the proposition that the curriculum design principles employed can lead to substantial training savings—a finding similar to that already reported in Task FORECAST.

Task MAINTRAIN

While FORECAST and JOBTRAIN were concentrated on the development of new courses of instruction, complete with supporting job aids and manual materials, the specific goal of Task MAINTRAIN was to develop an improved type of maintenance manual that would permit trained technicians to troubleshoot modern complex electronic systems faster and more accurately, and also to specify procedures for preparing such manuals. A literature review and analysis by the MAINTRAIN staff resulted in three conclusions:

(1) Troubleshooting tends to be more effective when procedures are specified in troubleshooting manuals than when the technician is required to develop his own procedures as he troubleshoots.

(2) Troubleshooting manuals that present detailed procedures for *all* troubleshooting steps in large systems will tend to be prohibitively large, and thus may be impractical and/or unusable.

(3) To be of *practical* value the troubleshooting manual must be based on a thorough understanding of (a) the problems encountered in troubleshooting and (b) the relative advantages of specifying procedures for troubleshooting versus providing information that will permit the technician to develop his own procedures.

By watching technicians perform troubleshooting on actual equipment and by careful interviewing to determine why they did what they did, researchers found that five distinct problems arose each time a check was made. These problems tended to be the same for each check regardless of the stage in the troubleshooting process. They were:

(1) Selection of a test point.
(2) Determination of the signal that should be present at the test point.
(3) Determination of a physical location of the test point.
(4) Determination of the signal that is present at the test point.
(5) Decision as to whether or not the signal present is "correct."

A careful examination of current electronics maintenance manuals, and of a variety of experimental manuals, indicated that no one of the available presentation techniques was suitable for presenting the information needed in all stages of troubleshooting—a not too surprising finding. Schematic diagrams, functional diagrams, block diagrams, troubleshooting charts, and written instruction for presenting troubleshooting information are all valuable presentation techniques for various kinds of information.

These lines of study and analysis led to hypotheses about the content and format of technical manuals, and these hypotheses were then tested. An experimental manual was prepared for use in troubleshooting the Nike Ajax missile and its associated test equipment. The manual was then evaluated by means of a test in which trained technicians had to locate malfunctions in the equipment. Two groups of recent school graduates were required to locate 44 malfunctions in the system—35 involving electronic malfunctions and 9 involving electrical malfunctions. The experimental group used only the

experimental manual, while the control group used the standard schematic and functional diagrams and personal notes they had made during the course. Troubleshooting by the group using the improved troubleshooting manual was substantially faster and more effective than that by the group using conventional manuals.

Thus, experimental evidence demonstrated that substantial improvements in troubleshooting could be obtained through improved manuals. The MAINTRAIN manuals differed from conventional manuals in two ways: (a) They presented some information not supplied in current manuals, and (b) the information was organized according to when and how it was to be used in troubleshooting. The improved manuals did not differ significantly from conventional manuals in size, and they contained all of the information presented in current manuals.

What has happened to the results of MAINTRAIN research? Various people within the Army have considered the MAINTRAIN approach to the construction of troubleshooting manuals and a variety of other approaches. However, there are currently no MAINTRAIN-type manuals in operational use.

Obviously, a change in the technical manual system represents a major and costly change in maintenance training and operation. However, MAINTRAIN has provided one tested approach to the problem of improving troubleshooting through improved manuals which is currently under consideration.

Task REPAIR and Task LIMIT

It is appropriate to mention briefly one aspect of work—a method of organizing training content—used in two separate tasks in the area of field radio equipment repair. The field radio repairman is a communications equipment maintenance man, responsible for higher echelon maintenance of up to two dozen different kinds of radios and smaller communications equipment. In the field radio repairman research programs, we followed the systematic seven-point approach to course development which was described earlier.

The particular aspect we would like to note here is the way in which we selected and sequenced course content—an approach we have called "functional context training." This training method is discussed in more detail in the following section, but its main features and the benefits derived from them are summarized in this description of representative research projects.

These are the principal features of the method, first stressed in Task REPAIR:

(1) A functional, maintenance-oriented context is clearly established for, and prior to, each block of instruction. At the beginning of a course this can be accomplished by giving the student an orientation in the operation of the system or the equipment that he must learn to maintain. No theoretical material is presented, except what can be shown in performance terms to apply to the job to be performed in the field.

(2) In teaching the equipment item, the various components are taken up in the same sequence in which they would be encountered by a maintenance man troubleshooting the equipment; that is, a "whole-to-part" sequence is followed.

(3) The student is presented with a graded series of job-related tasks. For successful performance each task requires that the trainee increase his knowledge of certain theoretical principles and/or that he acquire new skills. This is probably the most important feature of functional context training.

Organizing the instruction around the progressive series of job-related tasks can provide several benefits. First, this organization greatly facilitates the successful implementation of the other two principles. If information is presented as it is required for the performance of some job-related task, the establishment of a meaningful maintenance-oriented context is assured. Also, organization of instruction around a progressive series

of tasks usually means that each hardware item will be studied from the surface to the inside, not vice versa. Thus, the student encounters the various hardware parts in the sequence in which he will encounter them in troubleshooting.

Second, this method of organizing the course assures that the student is trained in the actual performance of job-related tasks. When instruction is organized on some other basis, there is a tendency to slight some of the job tasks and place perhaps too much emphasis on knowledges and skills which are *thought* to be necessary for job performance.

The third advantage of organizing courses by this method is closely related to the second. Since each bit of instruction is designed to teach a specific job-related task, and since all skills and knowledges are introduced as they are required for the performance of some job-related task, there is little need for guessing about course content. It is relatively easy to determine what skills and knowledges are required for each individual task, thus assuring that necessary content is included and that irrelevant knowledges and skills are omitted.

A final advantage of this approach is that a student is given a chance to apply each knowledge or skill soon after it is acquired. This helps the student to see that he is learning to do a job, not simply memorizing facts. And, it gives the instructor an opportunity to measure the student's ability to use the knowledges and skills he is acquiring.

In Task LIMIT, our use of the functional context technique proved itself convincingly with students of modest aptitude, although with higher-aptitude students it was neither more nor less successful than standard instruction. It appears to have some desirable motivational characteristics. For these two reasons, it was subsequently incorporated in Task HAWKEYE. This study on the Hawk missile system, which is described later in this paper, utilized the improved troubleshooting manuals developed in Task MAINTRAIN.

The functional context approach has been applied to a wide variety of Army courses, many of them outside the area of electronics maintenance training. The generality of this functional context principle appears to be great. HumRRO knows at first hand of its use in a two-week course in leader training for Army recruits, and in a statistics course at the university level—a wide range of usefulness for a notion that had its roots in electronics maintenance training research.

SOME GENERAL FINDINGS AND CONCLUSIONS

Distinction Between Education and Training

You will recall that, in the preliminary discussion of concepts, we drew a distinction between training and education. We believe this to be a most important distinction. Because of the characteristics of the manpower pool from which electronics maintenance technicians must be chosen, because of their relatively short period of availability for Army duty, and because of the variety of different military occupational specialties involved, HumRRO has strongly supported a training philosophy rather than an educational philosophy. It has been the HumRRO view that Army needs are best served by organizing electronics maintenance training to prepare a man to perform specific duties as dictated by the operational context in which the equipment is used and by the nature of the equipment itself. We believe that detailed and specific training objectives can, and indeed should, be established for the jobs to be trained. Such a philosophy might not be appropriate in other training contexts.

Some Distinctive Characteristics of HumRRO Research

In trying to identify some of the major, distinctive characteristics of the work HumRRO has undertaken in electronics maintenance training, we would include the following:

(1) Through a process of successive refinements, research has produced a generalized approach for the development of training courses—the seven-point procedure for curricular control which has been described previously. It is our belief that this approach is applicable to a wide variety of courses, not just to those in the maintenance area. It has been tested and has been found to be effective.

(2) Training in electronics and mechanical maintenance should be defined in terms of required on-the-job behaviors. The repairman should be taught to do those things that are required of him in the performance of his duties. The perspective of the trainers should be that of the man on the job (that is, the troubleshooter), not that of the equipment designer or of the trained engineer. Maintenance men are asked to maintain and repair equipment—they must be taught those skills and knowledges necessary to accomplish this goal.

(3) The selection of the course content to be taught also should be approached from the perspective of the troubleshooter. An analysis of the job to be performed should produce a list of the knowledges and skills that the trained man must possess. An analysis of the student's behavior repertoire before training will indicate that which does not have to be included in the course. Once content is selected, it should be sequenced in a fashion calculated best to achieve student mastery. The functional context approach is cited as one example of such a technique.

The Functional Context Method

The Functional Context Method, as noted earlier, grew out of a HumRRO research project to improve the training of Signal Corps electronics maintenance personnel. The project culminated in an experimental evaluation of the new course incorporating the method. The findings from this evaluation provided support for use of the method.

While it is described here in the context of radio repair training, the method can be generally applicable to instruction in both vocational training and educational settings. The problems encountered in radio repair training exemplify to a considerable extent the instructional problems facing trainers and educators in general. Central among these is the task of equipping the student with capabilities that are sufficiently general to enable him to cope with the multitude of varied problems he will encounter after completing training. For example, the radio repairman must possess skills and knowledge ranging from such relatively simple skills as soldering to the knowledge of general concepts that are needed in analyzing complex circuits.

The solution to training problems requires attention both to the relevance of the curriculum content to the goals of training, and to the effectiveness of the curriculum organization for learning efficiency. It sometimes is hard to separate these two aspects since instructional methods reflect content. However, the present discussion is focused primarily upon methods.

The main feature of the functional context method is its advocacy of a topic sequence wherein the *functional significance* of each topic is firmly established for the learner prior to, and as a context for, the learning of novel and more detailed material relating to the topic. Two requirements govern the choice of the learning context for any topic. First, the context must have significance for the learner; that is, it must be meaningful to him on the basis of previous learning in the course and ultimately his pre-course experience. Second, a context must have functional significance; that is, it must be directly relevant to the goals of the instruction.

As applied to a course in radio repair, the method is viewed as a means for facilitating the learning of basic electronics and maintenance skills and achieving a closer integration between them. Briefly, this accomplished through a topic sequence wherein basic electronics is taught within the broader contexts of over-all equipment function and maintenance. For example, the electronics principles governing the *internal* functioning of such circuits as oscillators and amplifiers are not taught until the learner has a clear understanding of the functions these circuits serve within more inclusive assemblies, such as radio transmitters or receivers. Thus, the functions of circuits provide contexts for learning the principles which govern their internal functioning.

The functional context method can be described most clearly by contrasting it with the traditional or conventional organization of topics in radio repair instruction.

(1) *The conventional sequence does not provide the learner with a meaningful and relevant context for the learning of novel and abstract material, particularly in the area of basic electronics.* The bulk of basic electronics is taught before the student becomes aware of its functional significance for the goals of training. At the time that Ohm's law, Kirchhoff's law, and so forth are taught, there is no reason to expect the beginning student to appreciate the importance of these electronics principles in over-all equipment functioning or troubleshooting. It is not surprising that many students have difficulty in grasping the concepts of basic electronics. The use of analogies—for example. comparing electron flow to water flow—represents one effort to provide meaningful contexts for the learning of basic electronics.

Another frequently used technique, which avoids the use of misleading analogies, is the analytic approach. Here, efforts are made to make concepts more meaningful by "explaining" them at more general levels of analysis. For example, current flow is said to be explained when it is shown to be derived from the flow of free electrons in a conductor, and so on. Unfortunately, the terms of the explanation are frequently even less meaningful to the student than the concepts being explained.

(2) *The abstract, unfamiliar material of basic electronics, when taught out of context, is unstimulating to many students, resulting in poor motivation for learning.* Instead of stimulating students, the new abstract concepts frequently frighten them. Moreover, instructors are apt to be unsympathetic toward students' negative reactions to basic electronics; because the instructors know the context, such abstract material is meaningful to them and they are unable to "put themselves in the shoes" of the student.

(3) *The conventional sequence places a heavy burden on the trainee to retain knowledge of basic electronics until the period in the course when it is to be applied.* Since a student lacks the relevant context for appreciating the importance of basic electronics at the time it is taught, he must rely on the instructor's guarantees that it has functional significance. Such "promissory notes" hardly provide optimal conditions for retention.

(4) A more important example of the reflection of method on content is the possible influence exerted by the deductive approach on the learning of troubleshooting methods. Troubleshooting characteristically involves a "whole-to-part" sequence in which detailed circuit analysis is begun only after the location of a trouble has been narrowed by a process of successive sectionalization to the point where a choice can be made among a few alternatives at the level of detailed circuitry. *The "part-to-whole" sequence of the conventional approach is in direct conflict with the "whole-to-part" sequence of troubleshooting and this conflict may handicap the learning of troubleshooting skills.* Troubleshooting instruction, placed toward the end of the course, is taught against a background of student orientation heavily weighted toward the "part-to-whole" approach. The confusion resulting from the conflict of approaches is believed to be responsible for two commonly observed deficiencies in the troubleshooting performance of newly graduated repairmen.

First, repairmen often are uncertain as to the first step to take in troubleshooting. Secondly, they are apt to engage in premature analysis of detailed circuitry in the early stages of troubleshooting.

The learning of effective troubleshooting methods may be handicapped in another way as a result of teaching basic electronics outside the maintenance context. In the teaching of basic electronics in its pure form, stress is placed on achieving an understanding of electronics in its pure form, stress is placed on achieving an understanding of electronic processes represented in *verbal* form. The apt student of this teaching becomes proficient in describing the intricate internal processes of circuits in such terms as electron flow, voltage changes, or polarization. At this stage in the training, little or no attention may be given to the measurement or testing techniques by which such processes can be verified objectively. The beginning repairman can get into considerable difficulty if he pursues circuit analysis on the purely verbal level without sufficient regard for feasible procedures for testing his hunches. It is believed that such practices are encouraged when basic electronics is taught outside the troubleshooting context.

Characteristics of Effective and Ineffective Technicians

As part of RADAR IV (1954-56) mechanics' training weaknesses were diagnosed on the basis of detailed behavior protocol records kept while the proficiency test was being administered to both experienced and inexperienced mechanics. Analysis of performance records showed a general training imbalance, with undue emphasis placed on theoretical analysis of circuitry at the expense of "lower level" but equally essential aspects of the maintenance job. For example, ineffective mechanics frequently attempted to make an elaborate schematic-diagram circuit analysis of a trouble and then, in spite of this, found themselves completely unable to physically locate the relevant circuitry in the system.

Specifically, the performance differences between effective and ineffective mechanics were as follows:

(1) Ineffective mechanics did not observe all gross symptoms appearing in malfunctioning equipment. They made fewer checks of system scopes, dials, meters, and other operational indicators than did effective mechanics.

(2) Ineffective mechanics, while troubleshooting, made fewer checks and manipulations of control settings (switches, handwheels, etc.) than did effective mechanics.

(3) Ineffective mechanics spent considerably more time hunting for physical location of system units and components than did effective mechanics.

(4) Ineffective mechanics referred earlier and oftener to schematic diagrams than did effective mechanics.

(5) Ineffective mechanics made more circuitry checks and measurements with test equipment than did effective mechanics.

(6) After isolating a suspected defective component, ineffective mechanics took more time before attempting component replacement than did effective mechanics.

(7) When replacing suspected components, ineffective mechanics more often failed to insert or connect the replacement parts correctly than did effective mechanics.

(8) After replacing suspected defective components, ineffective mechanics more often left interlocks open, or failed to return controls to operational settings, than did effective mechanics.

(9) After replacing suspected defective components, ineffective mechanics less often checked whether malfunction symptoms had disappeared than did effective mechanics.

THE HAWKEYE PROJECT

Task HAWKEYE was conducted by HumRRO at the US Army Air Defense School in the late 1960s. At the time it was considered by HumRRO to be a summation-type project to demonstrate to the Army the efficiency and effectiveness of job-oriented training programs for electronic technicians. This extensive curriculum-engineering project combined a training philosophy based on the functional context method with the previously demonstrated utility of systematically developed fault isolation manuals to be used as a training aid.

The HAWKEYE experimental program for training Hawk CW mechanics served as a prototype for the present course for training entry-level personnel in this MOS. Two observations concerning the original HAWKEYE course are believed to be relevant to an understanding of current military problems in this type of training. The first concerns the basic electronics content of the original HAWKEYE course, and the second concerns the reactions of field unit commanders to the HAWKEYE training program.

Basic Electronics Content. The original HAWKEYE course consisted of 24 weeks of training in which the basic electronics and system-unique knowledges were taught in the functional context of learning job-task skills. Basic electronics knowledges were an essential component of the training objectives; however, this fact was not obvious because these knowledges were taught in a system context and were not "front loaded," as was true of the then current conventional training program. As an example, the manner in which Ohm's Law was taught in the experimental course is described in detail in the following paragraphs.

The concepts of *voltage*, *current*, and *resistance* were introduced during the initial period of instruction concerning procedures for using the VTVM (TS-505). Presented below is an extract from the information provided students in a special text for the initial conference concerning the properties of voltages:

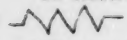
> The three quantities you will need to measure in electronic circuits are *voltage*, *current*, and *resistance*. *Voltage* is the power or pressure applied to a circuit which causes current to flow. *Resistance* limits the amount of current flow in the circuit.
>
> There are two kinds of current. *Alternating current (ac)* flows first in one direction, then the opposite direction, with very rapid alternations. *Ac voltage* is a voltage (or pressure) which causes ac current. Ac voltage is used in home wall outlets in the U.S., and in the HAWK system it is applied from the generator to the radars as their main source of voltage.
>
> *Direct current (dc)* flows constantly in one direction. *Dc voltage* is a voltage which causes dc current flow. Dc voltages are produced and used in many places in the CW radars.
>
> Voltage must always be measured between two points. One of these points is often called "ground" and may be physically hooked to the earth ground. The other point is usually called the "hot side" because if you touch it and ground (or are standing on the ground!), you may get shocked—or worse (burned—or buried).
>
> With dc voltages, ground is sometimes called the "reference point." Some dc voltages are positive (+) in respect to ground, and some are negative (–) in respect to ground.
>
> Voltages which you will measure at your lab position in these first blocks of instruction on meter use are called "source voltages" or "applied voltages," since they are voltages produced by a power supply (source) to be applied to a circuit. Voltages measured across part or groups of parts within circuits are often called "voltage drops," since they are voltages dropped by or used by individual parts. You will learn to measure these later in the course.

Subsequent blocks of the test equipment instruction provided additional information concerning electrical quantities and components. Following is an extract from the special text discussion of resistance. This training was given in conjunction with instruction concerning use of the Multimeter, TS-352A/U for making resistance checks:

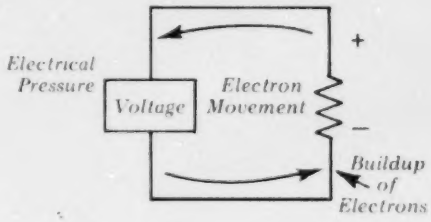
When you were introduced to using meters to measure voltage and current, you learned that there were three important quantities you would need to measure in electronic circuits—voltage, current, and resistance. Voltage, you may remember, is the power or pressure applied to a circuit which causes current to flow. Resistance opposes current flow, and thus limits the amount of current flowing in a circuit.

Various components are used in electronic circuits to provide resistance. Some components provide the same resistance to ac current as to dc current, and some components provide different amounts of resistance to ac current and dc current. The resistor is a very common component used in electronic circuits to provide the same resistance to ac current and dc current. Today you will use resistors to learn to measure the value of resistance. You will learn later about the resistance of other components.

The amount of resistance a component offers to current flow is measured in ohms. When we have large values of resistance, we use the term "kilohm" to represent 1,000 ohms and the term "megohm" to represent 1,000,000 ohms. The symbol for ohm is the Greek letter Ω (omega). The symbol for kilohm is K and the symbol for megohm is M.

In electrical diagrams (schematics), the symbol for the fixed resistor is  . The abbreviation for resistor is R.

The resistor, by offering opposition to current flow, will cause a voltage drop across it. There must be current flow in order to have a voltage drop. Current flow is the movement of negative charges (electrons). The resistor, by opposing current flow will cause a difference of potential across it, making one side negative in respect to the other.



This difference in potential is the voltage drop. The larger the resistance value of the resistor, the more opposition, therefore, the larger the voltage drop.

The relationship between current, voltage, and resistance is stated in a mathematical formula known as Ohm's Law. Ohm's Law states that the current (I) is equal to the electrical pressure (voltage) divided by the resistance (R).

$$I = \frac{E}{R}$$

In many cases resistors are used to reduce the voltage, that is, to drop a large voltage to a small voltage. This can be done by using a combination of resistors known as a voltage divider. By doing this, the same power supply can be used to supply circuits requiring different amounts of voltage.

The resistive value for some resistors is printed on the resistor. Others have colored bands around them. By knowing the color code of the hands, the value of the resistor can be determined. The use of resistor color codes will be covered in a later class.

Instruction in such electronics fundamentals was conducted in specially designed and equipped test equipment laboratories.

In contrast to the original HAWKEYE course, the instruction was later reduced from 24 to about 13 weeks, the special test equipment labs were eliminated, and the majority of BE instruction now is concentrated in a front-loaded two-week training program using lock-step classroom instructional methods. Considering these modifications to the design of the technical training programs for Hawk, it is highly likely that current graduates may not be as proficient as the men participating in the original version of the course. It should be noted, in passing, that the primary reason for reducing course length to 13 weeks was to have a training program for which draftees would be eligible. At that time draftees were not eligible to attend any course that exceeded 13 weeks in duration. Events have changed, and so has the quality of the student input. Perhaps it is time to re-examine the total training-utilization problem systematically.

Reactions of Unit Commanders. The opinions expressed by unit commanders concerning school training definitely can have an impact on the training establishment. Sometimes, however, these opinions lack validity. HumRRO TR 69-25[1] describes the results of a field followup of graduates of the initial Hawkeye classes. Field commanders at the battery level, assisted by their maintenance supervisors, evaluated the job proficiency of both HAWKEYE- and conventionally-trained technicians. This formal survey did not reveal any differences in the job proficiency of the two groups. However, later reports were received from commanders in the Pacific Theater that the HAWKEYE-trained technicians were ineffective and should have been given additional basic electronics instruction. A review of personnel assignments for the three experimentally trained classes revealed that only one HAWKEYE graduate had been assigned to that Theater; the men being criticized actually had received conventional instruction.

RESEARCH ON BASIC ELECTRONICS

The description of research in earlier sections of this paper concentrated on studies performed by HumRRO for the Army, particularly those associated with the training of air defense technicians, at both organizational and direct support levels. The other armed services have experienced similar training problems and have conducted extensive research programs in the field of electronics training.

U.S. Navy Surveys

In 1965 the US Naval Personnel Research Activity reported the results of a survey of electronics training in military and civilian training organizations.[2] This survey, which was patterned after a similar survey conducted by HumRRO in 1958,[3] yielded the following relevant conclusions:

> "Training Deficiencies. Although most of the observed electronics courses appeared fairly successful in achieving some training objectives, the single most common training deficiency was the lack of direct relationship between course content and realistic training objectives and criteria. Evidence of this difficulty appeared in varying degrees among the different courses, but it was generally

[1] *Development of a Procedure-Oriented Training Program for HAWK Radar Mechanics*, HumRRO Technical Report 69-25, December 1969.

[2] Sleinemann, J.H. *An Evaluative Survey of Electronics Training in Military and Civilian Organizations*, US Naval Personnel Research Activity Technical Bulletin 65-11, March 1965.

[3] Mager, R.F. *Current Practices In Electronics Training in Industry*, HumRRO Research Memorandum, May 1960.

apparent in such factors as: (a) the overemphasis of theoretical course content, (b) the retention of traditional subject matter in the course as a matter of precedent rather than on a basis of demonstrated need, (c) content difficulty level which was inappropriate to trainee input and course objectives, and (d) a volume of subject matter too great for reasonable comprehension and retention by trainees. Training personnel generally recognize these perennial problems, and various efforts are continuing toward reappraisal of training course content in terms of increased orientation toward actual job requirements. Despite these efforts, discrepancies exist in most courses between training methods and avowed training objectives. This remains a common area in which training improvement could be effected."

In 1969 the Navy Training Research Laboratory reported the results of an experimental program for training low aptitude (mental category IV) personnel assigned to electronics technician training.[1] This final report provided final evaluations of a training program in which much of the traditional basic electronics content had been eliminated, yet the lower aptitude graduates had been assigned to jobs like conventionally trained personnel. The final fleet follow-up was conducted after the experimentally trained technicians (X-ET's) had served in the fleet for approximately 24 months. The findings were described as follows:

"Since research limitations prevented the administration of performance tests in the final evaluation, the following summary statements are made on the basis of the supervisors' ratings. After two years of fleet service, the X-ET's were rated by their supervisors as being similar in overall technical performance to the matched sample of conventionally trained technicians. However, the A-ET's were rated as being more capable in the specific areas of electronics troubleshooting and in the use of test equipment. It should be noted that the lowest mean rating assigned to the X-ET sample was within the descriptive rating category comprising 'average' performance. Although at least 69% of both samples completed one or more courses beyond their original ET training and the expressed career intentions for both samples were highly similar, the A-ET's tended to be in higher paygrades than the X-ET's. Generally, the experimental ET program successfully trained marginally qualified personnel, in a relatively shorter period of time, to perform satisfactorily the duties of the Electronics Technician rating."

An Air Force Survey

In 1974, the Air Force Human Resources Laboratory reported on a study concerning the evaluation of the training of Air Force electronics maintenance personnel. The results of this study were as follows:[2]

"Results. Paper and pencil testing procedures are used almost exclusively for determining which personnel are selected for training, for determining student progress while in training and for determining the promotion eligibility of personnel assigned to field maintenance units. This analysis of reported research indicates that these measurement procedures do not insure that these personnel can perform the electronic maintenance tasks generated by the electronic hardware they are assigned to maintain. Most of the paper and pencil tests used in training and promotion concern theory and job knowledge. Studies are cited which indicate that extremely low correlations were obtained by comparing job task performance

[1] Van Matre, N.H. and Harrigan, R.J. *A Performance-Oriented Electronics Technician Training Program*, Navy Training Research Laboratory, NPTRL Research Report SRR 70-13, October 1969.

[2] Foley, J.P. *Evaluating Maintenance Performance*, Air Force Human Resources Laboratory, October 1974, AD/A-004-761.

tests to paper and pencil theory tests and to job knowledge tests. Several studies are also cited which indicate that the traditional theory content, found in most electronic maintenance training programs, does not contribute a great deal to the ability of an individual to perform electronic maintenance tasks. However, it is widely contended that a knowledge of theory is a necessary prerequisite to the successful performance of such tasks and this contention is deeply imbedded in the electronic maintenance culture. A full application of the modern technology for technical training development would solve the course content problem. This technology requires a systems approach to training program development in which training objectives are based on a complete job task identification and analysis."

Statistical Evaluations of Basic Electronics

A number of HumRRO studies of electronics maintenance training have included analyses of the role that basic electronics instruction may play in the development of system maintenance proficiency. These studies were specifically concerned with the training designed by the Air Defense School for radar mechanics.

The M-33 Radar Mechanic. The M-33 radar system was an integrated fire control system used in conjunction with 90mm and 120mm antiaircraft artillery weapons. That system was the predecessor of the Nike family of guided missile systems and shared many subsystems with Nike. In 1954-55, HumRRO conducted research to develop a job-oriented hands-on proficiency test for the M-33 mechanics and to evaluate their proficiency levels with a view toward subsequent research on training modifications. During that test-development effort, statistical evaluations were made of BE grades, system training grades, and proficiency on the hands-on test of over 100 mechanics who were tested immediately after graduation. That study found that the correlation between BE grade and Fire Control (FC) grade was 0.81. The *r* between BE grade and score on the proficiency test (PT) was 0.53. The *r* between FC and PT was 0.60. These results indicated that degree of achievement in the 12-week BE front-load course was highly related to achievement in the equipment training, but BE achievement was only moderately correlated with job proficiency.

Subsequently, a separate research effort was conducted to evaluate the system training achievement levels of students irrespective of their achievement in the BE subcourse. This study, conducted as Task RADAR IX, utilized a "no-turn back" policy, in which students were allowed to continue in training even if their achievement in BE dropped below the 70% level (at that time students normally were "boarded" and either re-cycled or dropped from BE training if their average achievement scores dropped below 70%). The M-33 training program consisted of 32 weeks of BE and weapon system training. The academic achievement of the 92 students participating in the "no-turn back" experiment were as follows:

(1) Upon completing three weeks of BE training, 46% of the students would have been recycled.
(2) After finishing the complete BE course (12 weeks), 29% would have been recycled or dropped.
(3) Upon completing the complete 32-week program, only 8% had to be boarded.

These results clearly indicated that although successful performance in BE was related to final course achievement, many students who were unsuccessful in BE could learn the system-specific knowledges and skills at an acceptable level. The intercorrelations obtained in the RADAR IX project were similar to those reported for the initial project: the correlation between final BE grade and final equipment grade was 0.85. The magnitude of this correlation again indicated that the high achievers in the basic

electronics course also tended to be high achievers for the equipment course. Whether this correlation could be assumed to imply causality had yet to be determined.

MAINTRAIN I: Short vs. Long BE. As indicated earlier, the conventional course for the M-33 mechanic included 12 weeks of basic electronics instruction. As part of an experimental curriculum engineering project (RADAR VI) the BE subcourse was reduced from 12 to 6 weeks. Since the graduates of the experimental course demonstrated higher maintenance proficiency levels than conventional students, it was considered desirable to evaluate the effects on that difference of reducing the BE subcourse.

In MAINTRAIN I two groups of about 40 students were given conventional instruction on the equipment, but one group was instructed in basic electronics using the texts and POI developed for the six-week experimental course. Both groups were given written and performance tests upon graduation from the equipment course. The written test consisted of 136 multiple choice items prepared by the department responsible for the BE instruction. A 15-item hands-on proficiency test was developed with the cooperation of the department responsible for equipment instruction. The results of the end-of-course testing program did not show differences between the two groups on either the written test or the proficiency test.

Retention of BE and Job Knowledges and Skills. The final study to be described was conducted in the context of the training of radar mechanics for the Nike Ajax guided missile system. This measurement study was similar to that performed for the M-33 mechanic in that estimates of maintenance task proficiency were obtained for personnel with increasing amounts of on-the-job experience. However, it differed from the M-33 study in that the retention of basic electronics subject matter was also measured.

The results indicated there was a "consistent trend for the experienced subgroups to score higher on the performance test and lower on the written (BE) test than the inexperienced group . . . ." The BE test scores decreased steadily during the first year of on-site experience. It was further reported that the correlation between BE test score and the proficiency test score was 0.34, which was statistically significant but not of great utility in predicting task proficiency. An additional observation, relevant to methological aspects, was that the ACB aptitude scores of the experienced men correlation 0.43 with the written test but only 0.10 with the performance test. That observation poses problems for evaluating causality vs. covariance of BE knowledge, job proficiency, and basic aptitude levels.

THE MILITARY PROBLEM RE-VISITED

There is a basic difference of opinion between Air Defense course developers and FORSCOM users concerning the kind of knowledges and skills that should be included in the training of organizational electronics technicians. This conflict of opinions is not new; it has been present continuously throughout the 20-plus years of research conducted in this area by a great number of training researchers in all the armed services.

The historical perspective of this paper touched upon only a small sample of the relevant research. A comprehensive survey of the *status quo* of technical training at various time points and a review of all the relevant research concerning task analytic methods, proficiency testing approaches, content derivation, and training evaluation would require a major research investment. The studies that were briefly reviewed in this paper were selected to point out the many variables that have been evaluated in the area of training electronics technicians, particularly in the context of Army training of radar technicians.

Previous research has repeatedly indicated that the degree of effectiveness of electronics technicians is not simply tied to the presence or absence of basic electronics instruction, although that controversy historically has been the stimulus for a considerable amount of the training-related research that has been conducted. HumRRO believes that it is essential to recognize that the causes of undesirable amounts of "equipment downtime"—the hypothesized basic military problem—may not be dependent upon the basic electronics sophistication of organizational mechanics. Inaccurate task analyses, inability or unwillingness to use systematic fault isolation procedures, lack of ability to use auxiliary test equipment, among other factors, could well be major contributors to the judgment that technicians are not trained adequately.